

# Has Information and Communication Technology Changed the Dynamics of Inequality? An Empirical Study from the Knowledge Hierarchy Perspective

*Research-in-Progress*

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## Abstract

*Wage inequality in the U.S. grew rapidly from the early 1980s, and information and communication technology (ICT) has been blamed for this social problem. Although information technology (IT) and communication technology (CT) have different effects, few empirical studies consider their distinct impacts on the dynamics of inequality. We examine the distinct impacts of IT and CT on inequality from the knowledge hierarchy perspective for the period 2004-2014, using comprehensive data on wages, employment, and ICT capital. Our findings suggest that IT and CT deepen wage inequality between the production and non-production layers. However, within the production layer, IT acts as a decentralizing force and CT acts as a centralizing force. Furthermore, ICT increases the relative demand for managers in the top layer and decreases demand for supervisors in the middle layer, contributing to job polarization. Our results imply the significant role of ICT in wage inequality, distinct from other technologies.*

**Keywords:** Skill-biased technological change, Knowledge hierarchy, Wage inequality, Span of control, Job polarization, Automation, Sustainability

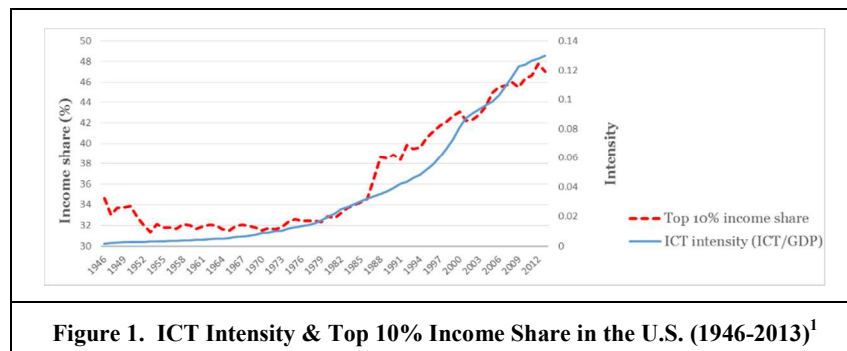
## Introduction

“Are we in danger of being destroyed by our own creations?”

- <Automation, Friend or Foe?>, Macmillan (1956)

Many researchers have discussed the negative consequences of technology. Job automation and wage inequality have been major topics in this discussion, at least since the Industrial Revolution in the 18<sup>th</sup> century. Wage inequality has grown rapidly since the early 1980s in the U.S., and most other OECD countries have experienced this phenomenon more recently (Autor et al. 2008; Van Reenen 2011). Since digital technologies have advanced tremendously in the past few decades, information and communication technology (ICT) plays a critical role, not only in productivity (Brynjolfsson and Hitt 1996), but also in employment and wage structures. Frey and Osborne (2013) argue that about 47 % of total U.S. employment is “at risk” from computerization.

Rapidly growing ICT could deepen wage inequality through skill-biased technological change, a phenomenon that seems like a “race between education and technology” (Brynjolfsson and McAfee 2011; Goldin and Katz 2008). The patterns in the top 10 % income share and ICT intensity in the U.S. seem very similar after World War II (Figure 1). While this is not direct evidence of causality from ICT to inequality, it strongly suggests a possibility of causality, leading information systems researchers to begin their recent focus on wage inequality. This study aims to provide empirical evidence related to the relationship between ICT and inequality.



Although most previous studies into the impact of ICT on organizations treat ICT as aggregate capital (e.g. Brynjolfsson and Hitt 2000; Ray et al. 2009), information technology (IT) and communication technology (CT) have different effects on organizations (Bloom et al. 2014) and even on the wage structure. However, there have been few empirical studies examining the distinct impacts of IT and CT on the dynamics of inequality in firm organizations. This study extends previous research on the relationship between ICT and inequality, though it differentiates between the impact of IT and that of CT.

Consistent with knowledge hierarchy theory, we examine the distinct impacts of IT and CT on inequality for the period 2004-2014 using the Occupation Employment Statistics (OES) data set provided by the U.S. Bureau of Labor Statistics (BLS) and ICT capital data set provided by the U.S. Bureau of Economic Analysis (BEA). The working population is divided into three groups by job description: Managers, (first-line) Supervisors, and Workers. Within the organizations, the first group is considered a non-production layer and the other two are classified as a production layer.

Our findings suggest that both IT and CT increase wage inequality between the production and non-production layers. However, within the production layer, IT acts as a decentralizing force decreasing wage inequality, and CT acts as a centralizing force increasing wage inequality. Interestingly, the differing results between ICT and R&D distinguish the effects of ICT on wage inequality from those of other technologies. Furthermore, ICT increases the relative employment demand for managers at the top layer, and decreases demand for supervisors in the middle layer, contributing to job polarization.

<sup>1</sup> We use ICT capital stock data provided by the BEA, and obtain the top 10% income share data from the World Top Income Database (<http://topincomes.parisschoolofeconomics.eu/>). It is worth noting that Non-ICT intensity is almost constant since the 1980s.

This study contributes to the literature in two ways. First, we differentiate between IT and CT, which affects firm organizations and wage structures differently. To the best of our knowledge, this is one of the first studies to attempt to empirically examine the distinct effects of IT and CT on wage inequality. Second, we link the role of organizational hierarchy to understand the dynamics of inequality. Although many previous studies examine the impact of technology on the labor market, this study investigates the effects of ICT on wage inequality and relative demand for employment on more than one type of hierarchical layer in organizations, providing deeper understanding of the effects of ICT on different types of jobs.

The rest of the paper is organized as follows: Section 2 surveys the relevant studies. In Section 3, we discuss the theoretical framework for an empirical analysis of the distinct impacts of IT and CT. We discuss the data and methods in Section 4. Section 5 provides the preliminary results of the empirical analyses, and their implications are discussed in Section 6 along with suggestions for future research.

## **Background**

### ***Skill-biased technological change***

“Digital technologies change rapidly, but organizations and skills aren’t keeping pace. As a result, millions of people are being left behind. Their incomes and jobs are being destroyed, leaving them worse off ...”

- <Race Against the Machine>, Brynjolfsson and McAfee (2011)

ICT investments have been substituting for other factors of production, including labor (Chwelos et al. 2010; Dewan and Min 1997), though the main issue here is that the substitution between ICT capital and labor occur disproportionately by skill level. Skill-biased technological change (SBTC) is a shift in production technology that favors skilled over unskilled labor by increasing its relative productivity, and thus its relative demand. SBTC has maintained upward pressure on the demand for highly skilled and educated workers while many lower skilled jobs have disappeared and median incomes have stagnated, contributing to increasing inequality. The “skill bias” attribute puts technological change at the center of the inequality debate (Acemoglu 1998; Machin and Van Reenen 1998). Recent studies suggest that ICT complements skilled labor (Autor et al. 1998; Bresnahan et al. 2002; Michaels et al. 2014). Bresnahan et al. (2002) show how the sharp decline in IT prices leads to a cluster of changes in IT use, organizational practices, and product innovation, thus increasing the demand for skilled labor. According to Frey and Osborne (2013), about 47 % of all U.S. employment is “at risk” from computerization, and education attainment is negatively associated with an occupation’s probability of computerization.

Although wage inequality rose monotonically in the 1980s, the changes in the wage distribution have become more complex since the early 1990s (Van Reenen 2011). The decline of the middle class has recently come to the forefront of the debate about inequality in the U.S. and other OECD countries (Autor and Dorn 2013; Autor et al. 2009). Many researchers suggest that ICT contributes to this “job polarization” by automating the routine tasks mainly performed by middle-skilled occupations (Acemoglu and Autor 2011; Autor et al. 2003; Michaels et al. 2014). ICT is likely to increase demand for non-routine cognitive tasks for high-skilled workers (e.g. CEOs). Since it is not yet easy to use ICT to automate non-routine manual tasks requiring hand-eye coordination and responses to the unforeseen (e.g. hairdressers and janitors), ICT has largely not affected the relative demand for low-skilled workers performing non-routine manual tasks. On the other hand, ICT substitutes for routine tasks significantly and decreases the demand for middle-skilled occupations, both manual (e.g. production workers) and cognitive (e.g. clerks).

### ***Distinct impacts of IT and CT on organization***

A large stream of studies cover the effects of ICT on organizations (Bresnahan et al. 2002; Brynjolfsson and Hitt 2000; Brynjolfsson et al. 1994; Gurbaxani and Whang 1991; Hitt 1999; Leavitt and Whisler 1958; Ray et al. 2009). Although most previous studies into the impact of ICT on organizations treat ICT as aggregate capital, IT and CT have different impacts on organizations (Bloom et al. 2014) and even on wage structures.

IT such as database systems and ERPs could act as a decentralizing or empowering force, allowing agents to handle more problems autonomously. Drucker (1988) suggests that the rise of IT will lead to

information-based organizations with a flatter structure and largely composed of autonomous specialists. Bresnahan et al. (2002) show that computer use is positively associated with decentralized organizations.

By contrast, CT such as networks and mobile technology could act as a centralizing force, leading to dependency on a few “superstars” (Rosen 1981). Gurbaxani and Whang (1991) argue that “decision information costs,” incurred by the communication costs and opportunity costs from delays in communication, increase as a decision right is moved upward in the organizational hierarchy. CT could reduce the decision information costs and lead to centralized management.

These differing effects from IT and CT influence organizations and wage structures. Bloom et al. (2014) empirically show that IT increases worker autonomy and plant managers’ span of control, while CT decreases worker autonomy. However, there have been few empirical studies of the impacts of IT and CT on wage inequality in firm organizations. Therefore, we examine the distinct impacts of IT and CT on wage inequality and relative demand for employment, consistent with knowledge hierarchy theory, as we discuss in the next section.

## Theoretical Framework

### Model

This study builds on “knowledge hierarchy” theory (Garicano and Rossi-Hansberg 2006; Garicano 2000) as the guiding theoretical framework for an empirical analysis of the distinct effects of IT and CT on inequality. The basic premise of the theory is that production requires labor and knowledge, consistent with knowledge-based view that posits knowledge as an essential resource for firms (Spender 1996).

Here, we briefly outline the simplified model of Garicano and Rossi-Hansberg (2006)<sup>2</sup>. In order to produce, agents should solve “problems,” such as operational and managerial decision making. If they can solve it, they produce; otherwise, they ask managers or supervisors for help. The possibility of offering help to others allows agents to organize themselves in the form of a knowledge hierarchy to use and communicate their knowledge efficiently. In this knowledge hierarchy, agents are specialized in production, constituting the lower hierarchical layer, or specialized in management, constituting the upper layer. Workers learn more common and easier problems to solve and managers learn “exceptions,” which are usually more difficult. Garicano (2000) shows that these hierarchical organizations are optimal assuming that agents do not know who knows the solution to the problem they cannot solve.

To the extent that the organization is determined by the economics of information and communication, ICT will change the optimal structure of the organization (Bresnahan et al. 2002; Gurbaxani and Whang 1991). Firms with a knowledge hierarchy will decide their optimal hierarchical structure in order to economize on the costs of acquiring knowledge and costs of communication. ICT generally affects the knowledge hierarchy in a way that IT can reduce the knowledge acquisition costs and CT can decrease the communication costs.

Consider the problem of a firm’s profit maximization under a knowledge hierarchy. A production worker draws a problem whose output is normalized to 1 per unit of time. Knowledge  $z$  is normalized in  $[0, 1]$  and knowledge acquisition cost is proportional to the knowledge level ( $a_i z$ ). Agents receive wages  $w$  depending on their knowledge level, and the wage function of knowledge is assumed to be increasing and convex, that is  $w'(z) > 0$  and  $w''(z) > 0$ <sup>3</sup>. Problems requiring knowledge  $z$  are distributed according to a probability density function  $f(z)$  whose cumulative distribution function is  $F(z)$ . Note that  $F(0)=0$ , and  $F(1)=1$  because knowledge is normalized in  $[0, 1]$ . In addition, we assume that the easier problem is, the more common the problem, that is  $f'(z) < 0$ .

A worker with knowledge  $z$  can solve a problem in expectation of  $F(z)$  and a fraction of  $1-F(z)$  requests managers for help. Helping a problem incurs a communication cost of  $h$  units of time ( $0 < h < 1$ ). Thus, total

<sup>2</sup> Garicano and Rossi-Hansberg (2006) present a general equilibrium theory considering heterogeneous agents’ problem to maximize income and firm’s problem to maximize profit. However, we only consider the firm’s problem, as in Bloom et al. (2014).

<sup>3</sup> Garicano and Rossi-Hansberg (2006) prove that the wage function of an agent’s ability is increasing and convex. Since agents’ ability can be represented as an increasing function of knowledge, we can obtain an increasing and convex wage function of knowledge.

time  $h[1 - F(z_L)]$  is required to handle problems referred by the worker per unit of time. For one worker, the firm needs to employ managers, at least as  $h[1 - F(z_L)]$ . Since output is 1 if the problem is solved, firms expect to produce with the probability of the highest knowledge level. For simplicity, we consider two layers: higher and lower represented by subscripts H and L, respectively. Under this knowledge hierarchy, the firm's profit per worker per unit of time is:

$$\text{Max}_{\{z_L, z_H\}} \pi = F(z_H) - [a_L z_L + w(z_L)] - n_H [a_H z_H + w(z_H)]$$

$$\text{Such that } h[1 - F(z_L)] \leq n_H$$

Without loss of generality, we normalize  $z_H = 1$ . For optimal production, the number in higher layer  $n_H$  is equal to the time needed. Therefore, the firm's profit maximization problem can be written as:

$$\text{Max}_{\{z_L\}} \pi = 1 - [a_L z_L + w(z_L)] - h[1 - F(z_L)][a_H + w(1)]$$

### Wage inequality

In accordance with the model, we capture the dynamics of inequality in firm organizations as two measures: *wage inequality* and *span of control*. Wage inequality is defined as the ratio of higher layer wages to lower layer wages. Since we normalize the knowledge of higher layer to 1, wage inequality corresponds to the inverse of the wage of the lower layer  $\left(\frac{1}{w(z_L)}\right)$  in the model.

Since  $f'(z) < 0$ , the second-order condition is met. Therefore, the optimal solution can be derived in a straightforward manner from the first-order condition. We set forth three propositions for wage inequality by the comparative static analysis.

**Proposition 1.** *If a reduction in knowledge acquisition cost for the upper layer is larger than for the lower layer  $\left(\frac{\partial a_H}{\partial a_L} > \frac{1}{hf(z_L)} > 1\right)$ , the reduced cost of acquiring knowledge ( $a_L$ ) increases wage inequality.*

**Proposition 2.** *If a reduction in the cost of acquiring knowledge for the lower layer is equal to or larger than for the upper layer  $\left(\frac{\partial a_H}{\partial a_L} \leq 1\right)$ , the reduced knowledge acquisition cost ( $a_L$ ) decreases wage inequality.*

**Proposition 3.** *The reduction of communication costs increases wage inequality.*

Since wage is an increasing function of knowledge, propositions 1-3 logically result from the change in the knowledge level  $\left(\frac{\partial z_L^*}{\partial a_L}\right)$ . According to the theory, IT, defined as information processing technology, will increase wages by reducing knowledge acquisition costs and increasing workers' knowledge levels. The theoretical prediction is consistent with previous studies, suggesting that workers who use computers (Krueger 1993) and office equipment such as calculators (DiNardo and Pischke 1997) earn more. Propositions 1 and 2 imply that the impact of IT on wage inequality is determined by the relative importance of IT for each layer. Proposition 3 implies that CT increases wage inequality because CT reduces communication costs, providing managers with cost advantages in problem solving.

### Span of control

Span of control is defined as the ratio of lower layer employment to higher layer employment (Garicano and Rossi-Hansberg 2006). In the model, span of control corresponds to  $\frac{1}{h[1 - F(z_L)]}$ . We set forth two propositions for span of control by the comparative statics.

**Proposition 4.** *If a reduction in knowledge acquisition cost for the upper layer is larger than for the lower layer, the reduced cost of acquiring knowledge decreases the upper layer's span of control.*

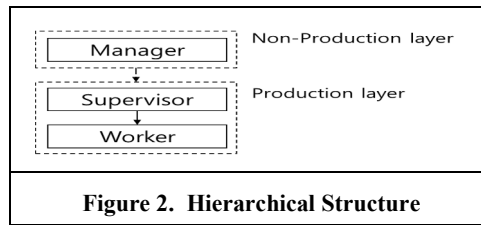
**Proposition 5.** *If a reduction in the cost of acquiring knowledge for the lower layer is equal to or larger than for the upper layer, the reduced knowledge acquisition cost increases the upper layer's span of control.*

Since IT affects wage inequality and span of control in the opposite way, propositions 4 and 5 are trivial results from propositions 1 and 2. However, CT affects span of control ambiguously. If the communication cost is reduced, more questions are asked (increase in  $[1 - F(z_L)]$ ), but each one takes less time (decrease in  $h$ ). If solving a problem is more important than reducing communication cost, CT will reduce span of control, and increase it otherwise. Span of control is negatively associated with relative demand for employment. If subordinates acquire more knowledge, they will require help less often and managers will take less responsibility in solving production problems. Consequently, span of control will increase because of the decreased cognitive burden on managers, and relative demand for managers will decrease.

## Methods

### Data description

We use industry-level data for the period 2004-2014 from two sources. First, we use data on wages and employment from the Occupational Employment Statistics (OES) program, provided by the BLS. The OES program produces annual employment and mean wage estimates for over 800 occupations classified by the Standard Occupational Classification (SOC) system. Since agents are specialized in production or in management in a knowledge hierarchy, we consider two layers: Non-production (managers) and Production. To further address inequality within the production layer, we divide it into workers and supervisors who directly supervise and coordinate workers' activities. Thus, the knowledge hierarchy consists of three layers: Managers (6.5% of employment and \$ 52.4 of hourly wage, on average), Supervisors (6.6% and \$ 27.4), and Workers (86.9% and \$ 16.9) (Figure 2)<sup>4</sup>.



Second, we obtain data on the capital stock and value-added for 22 goods-producing industries<sup>5</sup> in the U.S. private sector from the BEA. ICT capital stock is measured as the sum of the net stock from the “information processing equipment” category and “software” in the “intellectual property product” category. To investigate the distinct impacts of IT and CT, we measure CT capital as “communication equipment” in the “information processing equipment” category and we calculate IT capital by subtracting CT from ICT capital. IT capital includes software, computer and peripheral equipment, instruments, photocopy and related equipment, and office and accounting equipment. Note that we assume that IT and CT capital has a relatively larger impact on knowledge acquisition costs and communication costs, respectively.

We also consider research and development (R&D) and Non-ICT capital to control variables that could potentially affect wages and employment. Machin and Van Reenen (1998) find a strong positive relationship between the wage share of skilled workers and technology proxied by R&D intensity in seven OECD countries. We use “R&D capital” in the “intellectual property product” category as a proxy of overall technology. In goods-producing industries, most R&D capital relates to manufacturing and operation. Non-ICT capital includes non-ICT equipment (e.g. industrial equipment and transportation equipment) and structures. We use chain-type quantity indices as deflators for capital and value-added. Table 1 describes the variables contained in the data set.

<sup>4</sup> Managers include management occupations in a major group of 11. We define the production layer as production-related occupations in major groups of 41–53 (except 45–agriculture occupations), including sales, office and administrative support, construction/extraction, maintenance, production, and transportation occupations.

<sup>5</sup> Goods-producing industries consist of mining, construction, and manufacturing. Goods-producing industries have some merits to apply the knowledge hierarchy framework. First, knowledge hierarchies are prevalent in manufacturing industries (Garicano and Rossi-Hansberg 2006). Second, there are clear divisions between hierarchical layers compared to services-providing industries. We discuss potential limitations to generalizing our findings for the economy as a whole in the last section.

| Table 1. Summary Statistics : 22 industries in the U.S. (2004-2014) |                 |           |           |         |           |
|---|-----------------|-----------|-----------|---------|-----------|
|   |                 | Mean      | Std. dev. | Min     | Max       |
| (1)   | Value-added     | 124,991.0 | 143212.1  | 9,900   | 772,762.2 |
| (2)   | IT capital      | 7729.4    | 13833.9   | 414.3   | 75756.0   |
| (3)   | CT capital      | 1,504.7   | 1880.2    | 101.3   | 9,618.5   |
| (4)   | Non-ICT capital | 167535.4  | 232514.0  | 14023.2 | 1256998.0 |
| (5)   | R&D capital     | 36234.6   | 82602.2   | 424.2   | 474911.3  |
| Note: in millions of 2009 U.S. dollars                              |                 |           |           |         |           |

### Empirical model

To estimate the impacts of IT and CT, we consider the following empirical model of natural log form:

$$\ln(y_{it}) = \alpha + \beta_1 \ln\left(\frac{IT}{VA}\right)_{i,t-1} + \beta_2 \ln\left(\frac{CT}{VA}\right)_{i,t-1} + \beta_3 \ln\left(\frac{Non-ICT}{VA}\right)_{i,t-1} + \beta_4 \ln\left(\frac{R\&D}{VA}\right)_{i,t-1} + \sum INDUSTRY + \sum YEAR$$

$y_{it}$  denotes two dependent variables: *wage inequality* and *span of control* for each industry ( $i$ ) and year ( $t$ ). The natural log form avoids the problem of heteroscedasticity in the data set and interprets the coefficient as elasticity. For empirical analysis, we consider wage inequality and span of control between the production and non-production layers, and between supervisors and workers. Since the OES program estimates wages and employment in May and BEA estimates capital stock at the end of the year, we use lagged terms of independent variables in the empirical model. As independent variables, capital intensity is measured as capital per value-added (VA). In addition to capital intensities, we also include year dummies to control for year-specific effects common across industries (e.g. financial crisis) and industry dummies to control for time-invariant industry-specific effects.

### Results

Table 2 reports the results from estimating the aggregate impact of ICT and the distinct impacts of IT and CT on *wage inequality*. Columns 1 and 2 show the results of wage inequality between the production and non-production layers, and columns 3 and 4 present the results between supervisors and workers, both included in the production layer.

The coefficient of ICT intensity is positive and significant for non-production layer's wages relative to those in the production layer, and (insignificantly) negative for supervisors' wages relative to those of workers. These results are consistent with previous studies on the collapse of middle management (Leavitt and Whisler 1958) and job polarization (Autor et al. 2009).

In column 2, the coefficients of IT and CT are significantly positive, suggesting that both IT and CT contribute to wage inequality between the production and non-production layers. As discussed above, the impact of IT on wage inequality depends on the relative effects of IT in reducing knowledge acquisition costs for each layer. The results suggest that IT is more complementary for managers than for production workers, consistent with previous literature (Bresnahan et al. 2002; Michaels et al. 2014).

However, within the production layer, IT and CT have opposite effects on wage inequality between supervisors and workers, resulting in an insignificant aggregate impact of ICT (column 4). While CT increases wage inequality, as predicted by the theory, IT decreases the wage inequality between supervisors and workers. The results imply that IT has larger effects on workers than on supervisors. IT has recently enabled workers to self-organize without supervisory intervention (MacCrory et al. 2014) and to solve a wide range of production problems, so they require less access to their supervisors to inform their decisions (Bloom et al. 2014). Consequently, within the production layer, IT acts as a decentralizing force, and CT acts as a centralizing force.

Interestingly, R&D intensity decreases wage inequality between the production and non-production layers, and within the production layer, implying that the manufacturing and operating technologies proxied by R&D are more complementary to production workers. The results suggest the role of R&D as an equalizer within organizations, and distinguish ICT from other technologies in accounting for wage inequality.

| Table 2. Estimation Results of Wage Inequality                           |  |  |   |   |
|--|--|--|---|---|
|  | (1)  | (2)  | (3)   | (4)   |
|  | $\frac{W(\text{Non} - \text{production})}{W(\text{Production})}$ | $\frac{W(\text{Non} - \text{production})}{W(\text{Production})}$ | $\frac{W(\text{Supervisor})}{W(\text{Worker})}$ | $\frac{W(\text{Supervisor})}{W(\text{Worker})}$ |
| ICT intensity  | 0.053***<br>(4.01)   |  | -0.011<br>(-0.96)                               |   |
| IT intensity   |  | 0.032***<br>(2.84)   |   | -0.021**<br>(-2.12)                             |
| CT intensity   |  | 0.024**<br>(2.40)  |   | 0.023***<br>(2.69)                              |
| Non-ICT intensity  | -0.066***<br>(-5.05)   | -0.070***<br>(-5.05)   | 0.009<br>(0.75)                                 | -0.001<br>(-0.08)                               |
| R&D intensity  | -0.017**<br>(-2.19)  | -0.017**<br>(-2.11)  | -0.012*<br>(-1.68)                              | -0.013*<br>(-1.82)                              |
| R-sq(adj)  | 98.1   | 98.0   | 89.1  | 89.6  |
| Note: N=242, t statistics in parentheses; * p<0.1, ** p<0.05, *** p<0.01 |  |  |   |   |

Table 3 shows the results of estimating the aggregate impact of ICT and the distinct impacts of IT and CT on *span of control*. Columns 1 and 2 report the results between the production and non-production layers, and columns 3 and 4 present the results between supervisors and workers.

ICT intensity has a significantly negative impact on the non-production layer's span of control over the production layer, and a significantly positive impact on supervisor's span of control over workers. These results imply that ICT increases relative demand for the employment of managers in the top layer and decreases the relative demand for supervisors in the middle layer, contributing to job polarization. The result for supervisors is consistent with MacCrory et al. (2014), who demonstrate a significant reduction in the need for people to supervise routine work for the period 2006-2014.

In columns 2 and 4, IT and CT have opposing impacts on span of control. As predicted in the model, the impacts of IT on wage inequality and span of control are the opposite. However, the model has an ambiguous prediction for the impact of CT, as it depends on whether reducing communication costs or helping to solve problems is more important. IT significantly decreases the non-production layer's span of control, thereby increasing relative demand for managers. The coefficient of CT for the non-production layer's span of control over the production layer is positive and significant, implying that a decrease in communication cost has larger effects for managers than helping to solve problems. Reasonably, headquarters are usually apart from plants in goods-producing industries. Therefore, the reduced communication cost is probably more important for managers to manage production workers.

In the production layer, IT significantly increases the supervisor's span of control over workers, thus decreasing the relative demand for them. CT contributes negatively to supervisor's span of control over workers. The SOC system defines first-line supervisors as workers who spend more than 80 % of their time performing supervisory activities and coordinating workers' activities. For first-line supervisors, solving problems may be more important than reducing communication costs, resulting in a narrow span of control from CT. These results for the production layer are consistent with estimates by Bloom et al. (2014), which find that CAD/CAM as a proxy of IT increases significantly, and intranet as a proxy of CT decreases plant managers' (corresponding to first-line supervisors) span of control using plant-level survey data<sup>6</sup>.

Since ICT-producing industries (NAICS 334 - computer and electronic product manufacturing) inherently have tremendous ICT capital, we conduct an additional analysis excluding ICT-producing industries as a

<sup>6</sup> Our work differs from Bloom et al. (2014) in several ways. First, Bloom et al. (2014) focus on changes in plant manager and worker autonomy through IT and CT. While autonomy may be interrelated with wages, we investigate the changes in wage structures through IT and CT directly. Second, while Bloom et al. (2014) do not have direct measures for the corporate headquarters' autonomy and span of control, we estimate these using the direct measures of wages and employment.



robustness check. For brevity, we do not report the results, though all coefficient estimates remain unchanged for wage inequality and span of control.

| <b>Table 3. Estimation Results for Span of Control</b>                   |  |  |   |   |
|--|--|--|---|---|
|  | (1)  | (2)  | (3)   | (4)   |
|  | $\frac{E(\text{Production})}{E(\text{Non} - \text{Production})}$ | $\frac{E(\text{Production})}{E(\text{Non} - \text{Production})}$ | $\frac{E(\text{Worker})}{E(\text{Supervisor})}$ | $\frac{E(\text{Worker})}{E(\text{Supervisor})}$ |
| ICT intensity  | -0.138***<br>(-2.76)   |  | 0.069**<br>(2.16)                               |   |
| IT intensity   |  | -0.213***<br>(-5.38)   |   | 0.092***<br>(3.52)                              |
| CT intensity   |  | 0.107***<br>(3.06)   |   | -0.058**<br>(-2.50)                             |
| Non-ICT intensity  | -0.003<br>(-0.07)  | -0.029<br>(-0.59)  | -0.095***<br>(-3.02)                            | -0.072**<br>(-2.19)                             |
| R&D intensity  | 0.041<br>(1.35)  | 0.036<br>(1.25)  | 0.009<br>(0.46)                                 | 0.012<br>(0.61)                                 |
| R-sq(adj)  | 97.9   | 98.1   | 95.8  | 96.0  |
| Note: N=242, t statistics in parentheses; * p<0.1, ** p<0.05, *** p<0.01 |  |  |   |   |

## Discussion and Future Research

This study examined the distinct effects of IT and CT on inequality in terms of wages and span of control from the knowledge hierarchy perspective. Our findings suggest that IT and CT have deepened wage inequality between the production and non-production layers for the period 2004-2014 in goods-producing industries. However, within the production layer, IT acts as a decentralizing force and CT acts as a centralizing force. This study offers some plausible explanations for the inconsistent effects of ICT on organizational architecture, including wage structures and decision authority by differentiating IT from CT. Furthermore, ICT has increased the relative demand for top-level managers, and decreased the relative demand for supervisors in middle layer decreases, contributing to job polarization.

This study offers two main contributions to the literature. First, we differentiated between IT and CT, which affect organizations and wage structures differently. To the best of our knowledge, this study is one of the first attempts to empirically examine the distinct effects of IT and CT on the dynamics of inequality. Second, we examined the role of organization to understand the dynamics of inequality. Previous studies focus on the impact of technology on the labor market, but not organization-level mechanism, with a few exceptions (e.g. Bresnahan et al. 2002; Caroli and Van Reenen 2001). This study investigated the effects of ICT on wage inequality and relative demand for employment on more than one type of hierarchical layer, providing deeper understanding of the effects of ICT on different types of jobs.

Our study has some limitations to be addressed in future. First, although we examined the different effects of ICT in different layers in the organizational hierarchy, the effect of ICT would differ within the same layer. For instance, ICT would increase the wage inequality between “star” CEOs and “average Joe” managers in the same non-production layer. Investigating this issue will provide more implications for understanding the dynamics of inequality. Second, we included only goods-producing industries in the analysis. One should be careful about generalizing our findings for the economy as a whole because services-providing industries may be organized differently from goods-producing industries. Future studies should extend our empirical findings to the economy as a whole, including services-providing industries. Finally, although we have emphasized the importance of technology, especially ICT and R&D, there may be alternative explanations for skill upgrading and wage structures. For example, Fortin and Lemieux (1997) argue that the most important institutional changes – the decline in the real minimum wage, the decline in unionization rate, and economic deregulation – have significant effects on the rise in inequality. These explanations may complement the mechanism that we address in this study.

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